Steam End-User Training
Steam Distribution System Losses Module

__Slide 1 - Steam Distribution System Losses Module__

The steam distribution system typically consists of main steam headers, secondary or branch headers, condensate return piping, condensate collection equipment, as well as pipe and equipment condensate draining components. Often the distribution system is very large, extending to all areas of a facility. As a result, the distribution system can be a source of significant loss.

[Slide Visual – Steam Distribution Losses]

Banner:
DOE’s BestPractices
Steam End User Training

__**Steam Distribution Losses**__
Steam Leaks
Heat Transfer Loss Through Insulation
Condensate Loss
Overall System

__Slide 2 - Pipe Failures__

We will start our investigation in managing the distribution system losses by first focusing on leaks.

[Slide Visual – Steam Distribution Losses – Steam Leaks]

Banner:
DOE’s BestPractices
Steam End User Training

__**Steam Distribution Losses**__
Steam Leaks – Pipe Failures and Trap Failures
Heat Transfer Loss Through Insulation
Condensate Loss
Overall System

Slide 3 - Steam Leaks 1

This table indicates the maximum steam flow through an orifice or short section of pipe. It should be noted that the *discharge pressure* noted is the maximum backpressure at the orifice outlet for the calculation to be valid. Many (or most) leaks discharge to the atmosphere at 0 PSIG. However, this chart can be used for failed steam traps discharging to a closed condensate collection system that can be operating at an elevated pressure.

The table indicates a significant steam flow can pass through a relatively small opening. The amount of 100 PSIG steam that can pass through an orifice of one-sixteenth inch diameter is about 10 pounds an hour.

[Slide Visual – Steam Leak Rate (lbm/hr)]

This chart shows the Steam Leak Rate (pounds per hour) by Orifice Diameter

Steam Supply Pressure. The numbers on the left going up and down from one-sixteenth to one-half represent the Orifice Diameter in Inches. The numbers at the top going left to right from 20 to 500 indicate the Steam Supply Pressure in PSIG.

The Discharge Coefficient is 0.6 dimensionless.

Orifice Diameter (inch)	Leak Rate [lbm/hr] Steam Supply Pressure [psig]						
	20	50	100	150	300	400	500
1/16	3	6	11	16	30	39	49
1/8	13	25	43	62	119	157	195
3/16	30	55	98	140	268	353	439
1/4	53	98	174	249	477	628	780
5/16	82	153	271	390	745	981	1,218
3/8	118	221	391	561	1,073	1,413	1,754
7/16	161	300	532	764	1,460	1,924	2,388
1/2	210	392	695	998	1,907	2,513	3,118
	3	18	43	68	143	193	243
	Discharge Pressure [psig]						
Discharge coefficient	0.6	dimensionless					

At 100 psig steam supply and one-sixteenth inch orifice diameter, 11 pounds per hour of steam is lost due to leaks.

Slide 4 - Steam Leaks 2

If you consider that a steam cost of $10 per thousand pounds is a moderate cost—then even a small steam leak of 10 pounds per hour can result in a loss of more than $1,000 per year. The example steam system operates with a medium-pressure steam cost in the 15 dollars per thousand pounds range—as a result, this small steam leak would be more than 1,500 dollars per year. Steam leaks are very expensive and become enormous.

[Slide Visual – Steam Leak Rate (Cost per Year)]

This chart shows the Steam Leak Rate (in dollars per year) by Orifice Diameter.

Steam Supply Pressure. The numbers on the left going up and down from one-sixteenth to one-half represent the Orifice Diameter in Inches. The numbers at the top going left to right from 20 to 500 indicate the Steam Supply Pressure in PSIG.

The Discharge Coefficient is 0.6 dimensionless. The steam cost is 10 dollars per thousand pounds per hour.

Orifice Diameter (inch)	Leak Rate [$/yr] Steam Supply Pressure [psig]						
	20	50	100	150	300	400	500
1/16	300	500	1,000	2,600	3,400	4,300	1,400
1/8	1,200	2,100	3,800	10,400	13,800	17,100	5,500
3/16	2,600	4,800	8,600	23,500	31,000	38,400	12,300
1/4	4,600	8,600	15,200	41,800	55,000	68,300	21,900
5/16	7,200	13,400	23,800	65,200	86,000	106,700	34,100
3/8	10,400	19,300	34,200	94,000	123,800	153,700	49,200
7/16	14,100	26,300	46,600	127,900	168,500	209,200	66,900
1/2	18,400	34,300	60,900	167,000	220,100	273,200	87,400
	3	18	43	68	143	193	243
	Discharge Pressure [psig]						

Discharge coefficient	0.6	dimensionless
Steam Cost	10.00	$ per 1,000 lbm

At 100 psig steam supply and one-sixteenth inch orifice diameter, $1,000/yr of steam is lost due to leaks.

Slide 5 - Pipe Failures

Typically, even small steam leaks present significant savings opportunities. Often we are only interested in a general estimate of the cost of a steam leak in order to determine the repair strategy. Tables, like the ones shown here can be helpful in obtaining an order-of-magnitude opportunity associated with steam leaks. However, leaks can often be very difficult to estimate because of their irregular features. But, much of the time only a rough estimate of steam loss is necessary. Tables, like the ones presented here can aid in providing a gross estimate of steam loss.

Slide 6 - Steam Trap Management

Often the largest steam leaks in our industrial plants are difficult to detect. This is because most of the leaks result from failed steam traps and the steam traps discharge into closed condensate systems. Condensate collection systems are essential components in efficient steam systems but they can mask the steam loss from failed traps and make evaluating steam trap performance difficult.

A steam trap that is failed open can pass a large amount of steam because most steam traps have a restricting opening that is at least one-sixteenth inch diameter. Many steam traps have openings that are one-eighth inch diameter and even greater than one-half inch diameter. A one-eighth inch diameter orifice will pass four times more steam than a one-sixteenth inch diameter orifice. As we can see from the steam leak table the cost of a single failed steam trap can be enormous.

It is common for industrial facilities to have more than 10 percent and even greater than 30 percent of their steam traps failed. There are several failure modes and all of the failed traps will not be losing steam, but significant steam losses can occur when you consider that an industrial plant may have several thousand traps.

It is vital to properly manage the steam trap population by investigating the traps to determine if they are operating properly. It is necessary to inspect every steam trap in the facility and determine how it is performing. There are many different types of traps that function based on different principles. In order to investigate the steam traps it is vital to understand how each type works.

Slide 7 - Steam Traps

There are several common types of steam traps along with variations and combinations of types. We will now discuss the basic operating principles associated with the most common steam trap types.

[Slide Visual – Steam Traps]

Steam Traps
- **Thermostatic**
- **Closed Float**
- **Float and Thermostatic**
- **Open Float**
- **Thermodynamic**
- **Orifice**

Slide 8 - Thermostatic Steam Traps 1

A thermostatic steam trap operates based on temperature. Generally, the actuation results from an internal component expanding when temperature increases—and contracting when temperature decreases. When the trap internals are hot the trap valve is closed.

[Slide Visual – Thermostatic Steam Trap Closed]

Steam enters the steam trap from the bottom left. An internal component, a sealed bellows, represented by a 'spring-like" mechanism will expand with temperature increase, thus closing the trap with a plug at the bottom of the mechanism.

Slide 9 - Thermostatic Steam Traps 2

When the trap internals are cold the trap valve is open.

[Slide Visual – Thermostatic Steam Trap Open]

Steam enters the steam trap from the bottom left. When the liquid is sub-cooled, the internal component, a sealed bellows, represented by a 'spring-like" mechanism will contract, raising the plug at the bottom of the mechanism, allowing condensate or condensate and flash steam to flow out the other side of the trap.

Slide 10 - Thermostatic Steam Traps 3

When steam re-enters the valve the internals increase in temperature and the valve closes again.

Manufacturers use various methods to actuate the opening and closing activity with the common methods including bi-metallic strips or a fluid filled bellows.

An important operational point associated with a thermostatic steam trap is that the trap internals must cool to a temperature that is less than saturated steam temperature before the trap will open. Saturated steam and saturated condensate exist in the trap with exactly the same temperature. The trap will only open after steam has cooled and condensed and the condensate has further cooled to a sufficiently low temperature.

[Slide Visual – Thermostatic Steam Trap Closed]

Steam enters the steam trap from the bottom left. An internal component, a sealed bellows, represented by a 'spring-like" mechanism will expand with temperature increase, thus closing the trap with a plug at the bottom of the mechanism.

Slide 11 - Thermostatic Steam Traps 4

This trap will not discharge condensate immediately when it forms. The condensate must sub-cool before the trap opens—5 degrees Fahrenheit to 30 degrees Fahrenheit sub-cooling is typical. This type of trap is often considered the classic selection for heat tracing applications.

[Slide Visual – Thermostatic Steam Trap Open]

Steam enters the steam trap from the bottom left. When the liquid is sub-cooled, the internal component, a sealed bellows, represented by a 'spring-like" mechanism will contract, raising the plug at the bottom of the mechanism, allowing condensate or condensate and flash steam to flow out the other side of the trap.

Slide 12 - Closed-float Trap 1

The float type steam trap is arranged so that condensate enters a reservoir in the trap. The outlet valve is actuated by a float mechanism as the condensate level increases in the reservoir. The trap remains closed until the liquid level increases to the point that the float opens the outlet valve.

[Slide Visual – Closed Float Steam Trap]

Steam enters the trap and condensate collects in the reservoir. A float mechanism is used to control the condensate level in the trap. The condensate in the diagram is approximately half full in the reservoir and the plug closes the exit which will discharge the condensate.

Slide 13 - Closed-float Trap 2

As the condensate level increases the float inside the trap raises, which opens the outlet valve. Saturated liquid condensate passes through the outlet valve. As the saturated liquid condensate passes through the valve opening flash steam is formed.

[Slide Visual – Closed Float Steam Trap]

Steam enters the trap and condensate collects in the reservoir. A float mechanism is used to control the condensate level in the trap. The condensate in the diagram is nearly full in the reservoir. The float is raising and the plug opens the exit to discharge the steam and condensate.

Slide 14 - Closed-float Trap 3

The valve closes as the condensate level drops the float and valve arrangement.

[Slide Visual – Closed Float Steam Trap]

Steam enters the trap and condensate collects in the reservoir. A float mechanism is used to control the condensate level in the trap. The condensate in the diagram is approximately half full in the reservoir and the plug closes the exit which will discharge the condensate.

Slide 15 - Closed-float Trap 4

In the industrial arena a float type steam trap will always be coupled with another type of trap as a compound arrangement. Only liquid can exit the float type trap; therefore, the float type arrangement will not allow air or non-condensable gases to exit. This is why the float type trap is commonly coupled with a thermostatic type trap that provides air removal capabilities. This combined arrangement is identified as a *float-and-thermostatic trap*.

[Slide Visual – Closed Float Steam Trap]

Steam enters the trap and condensate collects in the reservoir. A float mechanism is used to control the condensate level in the trap. The condensate in the diagram is nearly full in the reservoir. The float is raising and the plug opens the exit to discharge the steam and condensate.

- **Rarely applied in this form in steam systems**
- **Opens to saturated condensate**
- **Will discharge condensate and flash steam**
- **Poor (no) air removal capability**

Slide 16 - Float and Thermostatic 1

Again, the float-and-thermostatic trap is a combination of two types of traps. When the trap fills with air, the air cools down triggering the thermostatic element to open.

[Slide Visual –Float and Thermostatic Steam Trap]

Steam enters the trap and condensate collects in the reservoir. A float mechanism is used to control the condensate level in the trap. A thermostatic element at the top of the reservoir allow air to enter, which when the air is cool, will cause the spring bellows to contract, opening the valve. The thermostatic element is closed in the diagram. The condensate in the diagram is nearly full in the reservoir. The float is raising and the plug opens the exit to discharge the steam and condensate.

Slide 17 - Float and Thermostatic 2

The thermostatic element can also open during startup conditions when the condensate load is heavy and subcooling has occurred.

[Slide Visual –Float and Thermostatic Steam Trap]

Steam enters the trap and condensate collects in the reservoir. A float mechanism is used to control the condensate level in the trap. A thermostatic element at the top of the reservoir allow air to enter, which when the air is cool, will cause the spring bellows to contract, opening the valve. The thermostatic element is open in the diagram and air can be seen leaving the thermostatic element. The condensate in the diagram is nearly full in the reservoir. The float is raising and the plug opens the exit to discharge the steam and condensate.

Slide 18 - Float and Thermostatic 3

This type of trap allows condensate to exit the system immediately after it forms making it an excellent selection for heat exchanger service and other applications where backing up condensate should be avoided.

[Slide Visual –Float and Thermostatic Steam Trap]

Steam enters the trap and condensate collects in the reservoir. A float mechanism is used to control the condensate level in the trap. A thermostatic element at the top of the reservoir allow air to enter, which when the air is cool, will cause the spring bellows to contract, opening the valve. The thermostatic element is open in the diagram and air can be seen leaving the thermostatic element. The condensate in the diagram is nearly full in the reservoir. The float is raising and the plug opens the exit to discharge the steam and condensate.

- **Opens to saturated condensate**
- **Will discharge condensate and flash steam**
- **Significant air removal and startup capabilities**
- **Modulating type operation**

Slide 19 - Open-float Trap 1

An inverted bucket trap is another type of float activated trap. An upside-down bucket serves as the float.

When the trap body and bucket are filled with condensate the bucket sinks.

[Slide Visual – Open Float Steam Trap]

Steam enters the trap from the bottom and moves an up-side down bucket upward. A cantilever at the top of the trap and bucket is used to open and close the steam trap outlet located at the top of the trap. The bucket mechanism will float upward and close the outlet valve of the steam trap. This diagram shows the bucket in a low position and the cantilever is low and allows the outlet valve to be open, releasing steam and condensate.

Slide 20 - Open-float Trap 2

Steam enters the trap under the bucket, this causes the bucket to float, which closes the outlet valve.

[Slide Visual – Open Float Steam Trap]

Steam enters the trap from the bottom and moves an up-side down bucket upward. A cantilever at the top of the trap and bucket is used to open and close the steam trap outlet located at the top of the trap. The bucket mechanism will float upward and close the outlet valve of the steam trap. This diagram shows the bucket in a high position and the cantilever is close to the outlet valve to close the outlet of the trap.

Slide 21 - Open-float Trap 3

The steam that lifts the bucket to close the valve must condense before the valve will open allowing additional condensate to enter the trap.

> ***[Slide Visual – Open Float Steam Trap]***
>
> **Steam enters the trap from the bottom and moves an up-side down bucket upward. A cantilever at the top of the trap and bucket is used to open and close the steam trap outlet located at the top of the trap. The bucket mechanism will float upward and close the outlet valve of the steam trap. This diagram shows the bucket in a low position and the cantilever is low and allows the outlet valve to be open, releasing steam and condensate.**
>
> **Non-condensable gases exit through a vent-hole at the top of the bucket and out through the valve.**

Slide 22 - Open-float Trap 4

Non-condensable gases entering the bucket will pass through a vent-hole at the top of the bucket and then out through the valve as the bucket begins to sink.

This trap is very effective in many applications.

> ***[Slide Visual – Open Float Steam Trap]***
>
> **Steam enters the trap from the bottom and moves an up-side down bucket upward. A cantilever at the top of the trap and bucket is used to open and close the steam trap outlet located at the top of the trap. The bucket mechanism will float upward and close the outlet valve of the steam trap. This diagram shows the bucket in a high position and the cantilever is close to the outlet valve to close the outlet of the trap.**
>
> **Non-condensable gases exit through a weep-hole at the top of the bucket and out through the valve.**
>
> - **Opens to saturated condensate**
> - **Will discharge condensate and flash steam**
> - **Limited air removal capability**
> - **Application in superheated steam service should be questioned**
> - **Intermittent operation**

Slide 23 - Thermodynamic Traps 1

Thermodynamic steam traps are designed with a solid metal disk in a control chamber. Condensate enters the control chamber under the metal disk pushing the disk up and out of the way. Condensate passes through the gap made between the disk and the trap body to the outlet, which is an annular channel in the trap body.

[Slide Visual – Thermodynamic Steam Trap]

Condensate enters upward through the trap, pushing a solid metal desk (represented by a green rectangle) out of the way, allowing steam to fill the chamber by flowing around the disk. When the disk is raised, steam and condensate can leave the trap.

Slide 24 - Thermodynamic Traps 2

When steam comes in, the velocity through the gap is much greater than that of the condensate; this results in an area of low-pressure. The control chamber will fill with relatively low velocity steam, which results in a high-pressure area on the top of the metal disk. Therefore, there is a pressure difference acting on the disk—high-pressure on the upper surface of the disk and low-pressure on the lower surface at the gap. This results in the disk slamming the trap closed.

It remains closed until the steam in the control chamber turns into condensate reducing the pressure above the disk opening the trap.

[Slide Visual – Thermodynamic Steam Trap]

Condensate enters upward through the trap. The solid metal desk (represented by a green rectangle) is blocking the passage of steam and condensate from entering the chamber. There is existing steam and condensate in the chamber that cannot be released to the outlet of the trap due to the location of the disk.

Slide 25 - Thermodynamic Traps 3

The trap will remain open releasing condensate. If steam is present the trap will quickly close again.

[Slide Visual – Thermodynamic Steam Trap]

Condensate enters upward through the trap, pushing a solid metal desk (represented by a green rectangle) out of the way, allowing steam to fill the chamber by flowing around the disk. When the disk is raised, steam and condensate can leave the trap.

Slide 26 - Thermodynamic Traps 4

This trap is very effective in many applications.

> ***[Slide Visual – Thermodynamic Steam Trap]***
>
> **Condensate enters upward through the trap. The solid metal desk (represented by a green rectangle) is blocking the passage of steam and condensate from entering the chamber. There is existing steam and condensate in the chamber that cannot be released to the outlet of the trap due to the location of the disk.**
>
> - **Opens to saturated condensate**
> - **Will discharge condensate and flash steam**
> - **Intermittent operation**
> - **Can be equipped with thermostatic element to improve air removal**

Slide 27 - Orifice Steam Traps 1

An orifice steam trap makes use of the drastically different properties of condensate and steam to regulate the throughput of the trapping device. Orifice traps do not have any moving parts but rely on a restricting orifice, small diameter short tube, or Venturi type nozzle as the primary working component. The density of condensate is anywhere from one order-of-magnitude to three orders-of-magnitude greater than the density of steam. This fact allows a significant amount of condensate to pass through a small opening and a minimal amount of steam to pass through the same opening.

> ***[Slide Visual – Orifice Steam Trap]***
>
> **Condensate passes through a restriction (represented by a narrow gap) and leaves as flash steam and condensate.**

Slide 28 - Orifice Steam Traps 2

In fact, when condensate is present the restriction acts as a regulating mechanism. This occurs because as condensate passes through the restriction pressure drop will cause flash steam to form in the condensate flow. This flash steam formation will restrict the flow that can pass through the device.

> ***[Slide Visual – Orifice Steam Trap]***
>
> **Condensate passes through a restriction (represented by a narrow gap) and leaves as flash steam and condensate.**

Slide 29 - Orifice Steam Traps 3

This type of trap has no moving parts, which serves as the main benefit of this device—maintenance requirements are low. It is critical to properly size this type of trap. If the trap is larger than necessary then significant amounts of live-steam will be lost to the condensate system. If the trap is smaller than necessary then condensate will backup into the system. Even though the main benefit of this trap is reduced maintenance requirements; proper sizing can lead to a small orifice diameter in the trap. This can become easily plugged with debris. .

[Slide Visual – Orifice Steam Trap]

Condensate passes through a restriction (represented by a narrow gap) and leaves as flash steam and condensate.

- **No moving parts**
- **Continuous operation**
- **Common applications are steady loads**
- **Limited air removal capability due to orifice limitations**

Slide 30 - Steam Trap Failures

In order to investigate steam traps, we must understand how they operate and how they fail. There can be many different failure modes for steam traps that can make managing the trap population difficult. However, it is good to note that two failure modes, in particular, typically provide the greatest impact to an industrial site. The first failure mode that impacts sites most significantly is when a trap fails closed. A failed closed steam trap typically does not waste energy; however, the economic impact can far exceed energy costs. This is because the device that is served by the failed steam trap will not be functioning properly. This can cause reduced production rates, poor quality, and water-hammer related failures.

The other failure mode that impacts sites most significantly is when a trap fails open, blowing a significant amount of steam. This failure mode obviously wastes steam and results in energy loss.

Again, there are other failure modes including leaking and intermittent operation, but these two failure modes impact site operations most significantly. This is actually good news, because these two types of failure are the easiest to identify. A steam trap failed open and blowing will exhibit high temperature and high noise. If the outlet of the trap can be seen the steam plume will be a direct indicator of the failure. Even if the trap discharges to a closed condensate collection system, the condensate receiver steam plume is an excellent indicator. Often this type of failure presents elevated pressure in the condensate return piping and can even result in presenting enough backpressure on other steam traps in the system, so they are not capable of functioning properly. Water-hammer in the condensate system is also a symptom of open and blowing steam traps.

On the other hand, steam traps that are failed closed will exhibit low temperature and no sounds of operation. It is not recommended to look only for open blowing steam traps and closed steam traps; however, the identification and repair of these types of failed traps has the potential of significantly improving steam system operations.

[Slide Visual – Steam Trap Failures]

- **Failure modes**
  - **Failed closed**
  - **Failed open**
  - **Failed partially leaking or partially closed**
- **Failed open and failed closed result in the greatest system impacts**
  - **These failure modes are the most readily recognized**
  - **These failures should be of first priority**

Slide 31 - Trap Investigation

The common tools used to investigate steam trap operation are temperature, sound, and sight.

[Slide Visual – Steam Trap Investigation]

Steam Trap Investigation

- **Visual**
- **Acoustic**
- **Thermal**
- **Combined methods**
- **In-line monitoring**

Slide 32 - Visual Trap Investigation

Steam traps that have visible outlets can often be easily identified as properly operating or failed. However, most of the steam traps in the industrial sector are connected to closed condensate systems because we want to recover the condensate and flash steam.

[Slide Visual – Visual Steam Trap Investigation]

- **Limited in applicability**
  - **Most condensate systems are closed**
  - **Safety and practicality limit use of this method**
- **Individual trap operation must be understood**

Slide 33 - Acoustic Trap Investigation

As a result, we must use listening devices and thermometers as our primary investigation tools. Ultrasonic instruments can provide excellent diagnostic capabilities.

[Slide Visual – Acoustic Steam Trap Investigation]

- **Many instruments are available**
- **Individual trap operation must be understood**
- **Ultrasonic sensing is typically the most practical**

Slide 34 - Thermal Trap Investigation

Contact thermometers and thermal imaging instruments can provide excellent support.

[Slide Visual – Acoustic Steam Trap Investigation]

- **Many instruments are available**
- **Individual trap operation must be understood**
- **Data can be inconclusive**

Slide 35 - Combined Trap Investigation

Combining investigation methods is the best analysis methodology.

In order to implement a world-class steam trap management program each trap must be investigated frequently—at least annually. The investigation must determine if the trap is functioning properly or if it is in a form of failure. If the trap is failed, the failure mode must be identified.

For traps that are failed open and blowing, an estimate of the steam loss should be developed. This will allow a repair priority to be established. Accurately evaluating steam loss through failed traps and leaks can be very difficult. However, keep in mind that we are really interested in the order-of-magnitude of the loss. As a result, a simple estimating technique can be useful. Steam traps are designed with a restrictive valve, opening, or channel—a limiting flow area.

Using this limiting orifice and the steam pressure in the trap the maximum steam loss possible can be calculated. There are many factors that can impact the actual flow through the trap; but, they should decrease the actual flow rather than increase it. A dominant factor is if some of the internal trap components partially block the opening. Alternately if a significant portion of the flow is condensate, the steam loss will be reduced; however, it takes a very large condensate flow to reduce the steam flow significantly. A simple orifice calculation or a table like the one presented previously in this training can provide a foundation for an order-of magnitude steam loss estimate.

Slide 36 - Trap Investigation

Additional investigation points should also be targeted when determining if each trap is functioning properly or not. Identifying if the trap is the correct type for the application is an important investigation. Evaluating if the trap is installed properly is very important.

Each trap will experience two-phase flow not only exiting the trap as flash steam forms but also entering the trap as steam pushes condensate through the trap. In fact, in many applications, the trap inlet piping will experience two-direction flow as the steam in the trap body is displaced by condensate

entering the trap. And do not forget that non-condensable gases will also be present in the steam system. As a result, we'd like to have the trap inlet pipes as short, as big, and as straight as possible. Gravity should be the primary force allowing condensate to flow into the trap and the pipe arrangement should allow steam to flow out.

Slide 37 - Trap Survey Investigation

Another good question to ask of each trap is if condensate is collected from the trap. It is important to investigate if the condensate is actually being collected or if some problem is preventing the condensate from being returned to the boiler with the highest practical temperature. Recall that there are many excellent reasons to recover condensate, but the primary worth of condensate resides in its temperature. Condensate needs to reach the boiler with the highest practical temperature.

Very often, effective condensate recovery is hampered from poor design of the return piping. Many times the return piping is tasked with transporting both liquid condensate and flash-steam. Often the mass flow of flash-steam is a relatively small portion of the total flow, but because the density of the flash-steam is very low, the volume flow of the flash steam can be a large portion of the total volume flow. This can result in water-hammer problems and backpressure issues. The problem can be exacerbated if a steam trap fails open discharging live steam into the condensate system. There can be a significant amount of energy in the flash-steam; but, if it is resulting in the loss of all the condensate, then it may be best to vent the flash steam from the system and pump the liquid condensate back to the boiler.

Slide 38 - Maintenance Program 1

A world-class steam trap management program will incorporate all of these aspects to ensure the steam traps and collection systems are operating at peak performance.

Every steam trap in the facility should be evaluated at least one time each year. The evaluations should be completed by trained personnel that understand the operation of steam traps and the steam system in general. Steam trap functionality should be assessed through the use of appropriate instruments like ultrasonic sensors and thermometers.

The assessment results should be compiled in a database that includes the analysis result for the trap—good, failed leaking, failed blowing, failed closed.

A loss estimation for each failed leaking trap should be established. This will be an estimate of the steam loss from the failed trap. An excellent method to establish the maximum steam loss through a failed trap is to obtain the diameter of the trap valve opening—this is the minimum opening restricting the steam flow. This information along with the operating pressure of the trap can be used to complete an orifice calculation to determine the maximum steam flow that can pass through the steam trap if the trap is failed in an unobstructed manner. This will serve as the maximum steam loss for a particular trap. Difficulty arises in identifying if a trap is failed with no internal obstructions or partially obstructed and if the trap is partially obstructed then what fraction of the maximum flow should be assigned to the trap. However, an order-of-magnitude loss estimate is generally sufficient to allow repair prioritization to occur.

Additionally, the trap discharge pressure should be considered because the trap backpressure can reduce the maximum steam flow that can pass through a restriction.

During the steam trap assessment, additional investigations should be targeted. For example, each installation should be evaluated to determine if the most appropriate trap type has been installed. Steam traps must be installed properly to function appropriately. This is true for the trap orientation and for the trap inlet and outlet piping. The trap piping will be required to carry two-phase flow, which significantly impacts the design. Commonly trap inlet piping will also require two-direction flow as condensate displaces steam in the trap and piping. Many additional installation factors should be considered.

The steam trap investigation is an excellent time to determine if condensate is recovered from the trap. If condensate is not recovered the recovery strategy should be investigated.

[Slide Visual – World Class Steam Trap Maintenance Program]

- **Training is essential.**
- **Investigate each trap at least one time each year (problem areas and high pressure should be more frequent)**
  - **Performance**
    - **Testing equipment is required**
    - **An order of magnitude leak rate should be determined for failed traps**
      - **Orifice calculations set the maximum steam flow**
  - **Trap type**
    - **Trap selection should match the application**
    - **Universal mounts can be a good option**
  - **Installation**
  - **Establish an investigation route**
  - **Condensate return**
  - **Outsourcing can be a good option**

Slide 39 - Maintenance Program 2

During the steam trap evaluation process, each trap in the facility is identified—this is a good time to develop a database that includes each trap in the facility. This allows a history of each application to be developed.

A single steam trap failed open can result in significant economic loss for the site; making steam trap management essential for most facilities. An excellent diagnostic tool that can be employed at many facilities is to visually observe the atmospheric vents of the condensate receivers. Most steam traps will appropriately form flash-steam that will pass through the condensate receiver vents; but, excessive vent steam flow indicates failed steam traps.

[Slide Visual – World Class Steam Trap Maintenance Program]

- **Maintain a steam trap database**
- **Prioritize repairs based on loss estimates**
- **Daily monitor receiver vents**
- **Training is essential**

Slide 40 - Trap Selection 1

This is an example of the importance of steam trap selection. In this example a steam coil is serving an air handling unit on a drum oven. A drum oven is basically a room that can be filled with 55 gallon drums. The room (or oven) is sealed and air is circulated from the oven, through a steam coil, and back to the oven to heat the contents of the drums. In this particular case, the drums contained various petroleum products that were being supplied to a production plant.

The facility was developing a project to replace the drum oven with one of larger capacity because the drum oven was the bottleneck of the process. The production rate of the entire plant was limited because the drums could not be heated fast enough. We were requested to investigate the oven and determine the capacity the new unit should have to allow production to be increased.

The desired supply air temperature in the drum oven was 310 degrees Fahrenheit. However, we measured a supply air temperature of approximately 280 degrees Fahrenheit. The steam coil was supplied with steam through a fully open control valve and the steam pressure in the steam coil was essentially the same as the main supply pressure of 135 PSIG. The saturation temperature of the steam supply was 358 degrees Fahrenheit.

During our investigation we observed that the steam coil was served with a thermostatic steam trap. This trap was opening when the condensate temperature was 285 degrees Fahrenheit—more than 30 degrees Fahrenheit of subcooling. As a result, the steam coil was mostly filled with condensate. This dramatically reduced the amount of energy transfer.

[Slide Visual - Steam Trap]

The schematic shows an oven, basically a closed room. Air is circulated from a mix of makeup air and from the oven to the room and across a steam coil, mostly filled with condensate. The saturation steam is supplied at 135 psig and 358 degrees Fahrenheit through a control valve. AThermostatic steam trap discharges condensate at 135 psig and 285 degrees Fahrenheit.

Slide 41 - Trap Selection 2

Rather than replacing the drum oven we replaced the thermostatic steam trap with a float-and-thermostatic steam trap. Immediately the supply air temperature increased to the point that the steam control valve regained control of the oven. The drum oven replacement project was canceled.

[Slide Visual - Steam Trap]

The schematic shows an oven, basically a closed room. Air is circulated from a mix of makeup air and from the oven to the room and across a steam coil. The saturation steam is supplied at 135 psig and 358 degrees Fahrenheit through a control valve. A Float and Thermostatic steam trap discharges condensate at 135 psig and 358 degrees Fahrenheit.

Slide 42 - Insulation

Insulation is a very important aspect of all steam systems. Most steam systems have a large amount of steam and condensate piping located throughout the plant. Huge energy losses can result if the distribution system is not properly insulated.

[Slide Visual – Steam Distribution Losses –Heat Loss Through Insulation]

Banner:
DOE's BestPractices
Steam End User Training

Steam Distribution Losses
Steam Leaks – Pipe Failures and Trap Failures
Heat Transfer Loss Through Insulation
Condensate Loss
Overall System

Slide 43- Insulation Issues

The fundamental aspect of insulation can be thought of as "is it there or not". We are not trying to make light of the very important factors; such as, insulation type, insulation thickness, and installation methods. However, a short length of un-insulated steam pipe can experience the same loss as a very long length of poorly selected insulation. In other words, we are not advocating ignoring insulated pipe but the largest losses and most important opportunities typically reside in repairing areas with missing insulation, badly damaged insulation, or water related issues. Opportunities related to missing or badly damaged insulation typically have simple paybacks in the fraction of a year range.

Slide 44 - Missing Insulation

In order to emphasize the primary points associated with insulation we will examine an example. During our investigation of the steam system we observed a section of the main steam distribution piping to be un-insulated. This steam header is insulated for most of its length; but as shown in the picture, as it transitions from one side of the pipe-bridge to the other it is un-insulated.

There is about 20 linear feet of un-insulated pipe. Most of this pipe is horizontal but two short sections are vertically oriented. The nominal diameter of the header is 10 inches. The pipe contains medium-pressure steam and an infrared thermometer indicates the pipe surface temperature is 550 degrees Fahrenheit.

The calculations required to estimate the heat transfer reduction from installing thermal insulation are lengthy and complicated. U.S. DOE offers a specialized software tool that simplifies the analysis tremendously—the software tool is 3E-Plus.

[Slide Visual – Missing Insulation Photo]

- **A 20 foot long section of 150 psig header is observed to be un-insulated**
  - **10 inch nominal diameter**
  - **Steam temperature is approximately 550°F**

A photograph of an industrial pipe bridge is shown. The piping is somewhat congested but fairly typical of an industrial plant. One of the pipes, prominently displayed in the picture, is a steam header that has a section with no insulation. The un-insulated section has horizontal and vertical runs. This run has four 90-degree elbows which allow the pipe to avoid an obstruction. The piping distribution runs from left to right, engages an elbow to allow the piping to be raised, then an elbow to allow the piping to run toward the viewer and over a structural member, engage another elbow to turn down to the original elevation, then another elbow to continue to advance to the right. The pipe at the left of the picture is observed to be insulated with a metal jacket covering the assembly. However, in a very short distance the insulation and covering are removed leaving the pipe un-insulated through the turns and straight sections. Insulation and jacketing are in-place on the pipe as it leaves the picture to the right.

Slide 45 - 3E Plus Insulation Tool

3EPlus is designed to complete analyses on all common insulation projects. The software is very user friendly and very powerful. Let's use this tool to determine the economic impact of insulating the steam header we saw with the missing insulation.

[Slide Visual – 3EPlus Software]

The first screen of the 3E Plus Insulation tool is shown. It says "3E Plus Insulation Thickness Computer Program.

Determining your insulation needs has never been easier.

3EPlus Insulation Thickness Computer Program
- **Calculates Thermal Performance of Piping and Equipment**
- **Translates BTU Losses into Actual Dollars**
- **Calculates Greenhouse Gas Emissions and Reductions.**

Sections of the Program [buttons at top of page, descriptions on main screen]
Energy
- **Insulation Thickness**
- **Energy Loss/Gain**
- **Cost of Energy**

Environment
- **CO2 Reduction with Insulation Thickness**

Economics
- **Calculations for New Insulation Projects**
- **Calculations from Previous Projects**

Brought to you by NAIMA North American Insulation Manufacturers Association

Slide 46 - 3E Plus 1

The software opens to a page that allows the user to input specific data concerning the insulation opportunity. In this example we assume all of the pipe is horizontal; even though we know there are vertical sections of the pipe as well. We have selected this for simplicity—we can attain a more detailed result if the analysis is broken into horizontal and vertical sections.

It is good to note at this point that the 3EPlus software is based in the principles of heat transfer and physics and it rigorously solves the governing equations for each scenario. However, it should be noted that the variability of the real world parameters governing the situations is significant. As a

result, the analysis must be considered an estimate. For example, we will input a wind speed into the analysis as 3 miles per hour. There is significant real-world variability in wind speed and wind speed has a major impact on the energy loss from the piping system.

The remaining input data is straightforward. We are working with typical piping; as a result, we will select ASTM C-585, which is the designation for common piping. If you are working with tubing another selection can be made.

There are many calculation types that can be selected from. In this example we will choose Heat Loss per Year. This will set the calculation results to an annual basis.

We have measured the pipe surface temperature to be 550 degrees Fahrenheit, which can be taken as the Process Temperature. Ambient Temperature is taken as 70 degrees Fahrenheit, which is conservatively high for the annual average ambient temperature.

The pipe is a 10 inch Nominal Pipe Size or NPS. The wind speed has been selected as 3 miles per hour.

The steam system serving this site is in operation 24 hours a day and 365 days a year; in other words, 8,760 hours per year.

All of this information in the upper portion of the page is basic to the analysis. Now in the lower section of the page we select the specific insulation properties.

The pipe material is steel. The insulation that is in-place on the remainder of the pipe is calcium silicate. Because we are addressing a short section of existing piping and insulation we will most probably install the same insulation and jacket material the rest of the system has. However, it is good to note that the software has the properties of the common insulation materials built in. The insulation on the remainder of the pipe is 3 inches thick and covered with an aluminum jacket. This jacket will be oxidized in service fairly quickly.

[Slide Visual -3EPlus Energy Tab – Insulation Thickness]

Insulation Thickness –
Surface Temperatures
Condensation Control
Personal Protection

Energy Tab
Insulation Thickness (Data Entry Screen)
Item Description: missing insulation
System Application: Pipe Horizontal
System Units: ASTM C585
Calculation Type: Heat Loss Per Year
Process Temperature :550.0 F
Ambient Temperature: 70.0 F
NPS Pipe Size: 10
Wind Speed: 3 mph

Annual Operation: 8760 hours per year

Insulation Layers
Add Button
Delete Button

#	Type	Name	Lock Thickness	Thickness, Inches
-	Base Metal	Steel		
1	Insulation	BLK+PIPE, Type I, C533-07	Fix	3
-	Jacket Material	0.1 Aluminum, oxidized, in service 07		

Slide 47 - Insulation Evaluation

When the Cost of Energy selection is made the user is allowed to input fuel cost which is used to evaluate the economic impact associated with installing the selected insulation.

Fuel type along with fuel higher heating value also become input parameters.

Another input parameter is Efficiency. This Efficiency is in reference to the fact that for every unit of thermal energy loss eliminated even more fuel energy consumption is eliminated. The main contributor to this additional loss is boiler efficiency. As a result, inputting boiler efficiency will more accurately identify the fuel cost impact associated with installing insulation.

[Slide Visual -3EPlus Energy Tab – Cost of Energy]

Cost of Energy –
Bare and Insulated Surfaces

Energy Tab
Insulation Thickness (Data Entry Screen)
Item Description: missing insulation
System Application: Pipe Horizontal
System Units: ASTM C585
Fuel Type: Natural Gas
Heat Content: 1000 BTU/cubic foot
Fuel Cost: 10.00 $/Mcf
Efficiency: 80 percent
Process Temperature :550.0 F

Ambient Temperature: 70.0 F
NPS Pipe Size: 10
Wind Speed: 3 mph
Annual Operation: 8760 hours per year

Insulation Layers
Add Button
Delete Button

#	Type	Name	Lock Thickness	Thickness, Inches
-	Base Metal	Steel		
1	Insulation	BLK+PIPE, Type I, C533-04	Fix	3
-	Jacket Material	0.1 Aluminum, oxidized, in service 07		

Slide 48 - Insulation Savings

The software calculates the energy loss from the uninsulated pipe and for the insulated pipe. The difference in these two energy losses is the savings opportunity associated with installing insulation. The boiler fuel impact is calculated as more than $600 per year for every foot of un-insulated pipe. In other words, insulating 20 feet of un-insulated pipe will reduce fuel purchases approximately $12,000 per year.

[Slide Visual – 3EPlus – Cost of Energy]

Cost of Energy –
Bare and Insulated Surfaces

Energy Tab
Item Description = Missing Insulation
System Units = ASTM C585
Geometry Description = Steel Pipe - Horizontal
Bare Surface Emittance = 0.8
Nominal Pipe Size = 10 in.
Process Temperature = 550 °F
Ave. Ambient Temperature = 70 °F
Ave. Wind Speed = 3 mph

Fuel Type: Natural Gas
Heat Content: 1000 BTU/cubic foot
Fuel Cost: 10.00 $/Mcf
Efficiency: 80 percent
Hours Per Year = 8760
Outer Jacket Material = Aluminum, oxidized, in service
Outer Surface Emittance = 0.1
Insulation Layer 1 = Calcium Silicate BLK+PIPE, Type I
Thickness: 3.08 in.

Append to Audit - Browse

Variable Insulation Thickness	Cost ($/ft/yr)	Heat Loss (Btu/ft/yr)	Savings ($/ft/yr)
Bare	636.90	50950000	
Layer 1	28.74	2300000	608.200

Savings = 608 $/ft-yr (20 ft) – 12,000 $/hr

Slide 49 - 3E Plus 2

3EPlus also incorporates an estimating tool that allows insulation purchase and installation costs to be evaluated. This tool incorporates standard costs for insulation materials and insulation jacked materials. These standard costs can be adjusted by the user to reflect local costs. Additionally, the tool estimates the time required for an insulating crew to install the materials. The user is allowed to input local labor rates along with construction difficulty rates. These items allow the purchase and installation costs to be estimated for the insulation project. This cost estimating tool is found in the Economics section of 3EPlus.

Using the project estimator in 3EPlus this project would require approximately 600 dollars to complete. In other words, this is a very attractive project.

[Slide Visual – 3EPlus – Project Costs]

($28.76 per Linear Foot) (20 Linear Feet) ~ $600 Project Costs

[Slide Visual – 3EPlus - Economics Tab]

Thickness Calculations

New Project

Economics Tab

Cost and Thickness Data

Surface number: 17

Pipe Size: 10

<u>Single Layer</u>

Thick	Cost
1	0.00
1.5	18.05
2	22.20
2.5	25.61
3	28.76
4	35.82

<u>Double Layer</u>

Thick	Cost
3	32.26
4	41.82
5	51.54
6	61.29
0	0.00
0	0.00

<u>Triple Layer</u>

Thick	Cost
6	69.17
7	81.04
8	92.83
9	99.73
10	115.57
0	0.00

Back, Next, and Calculate buttons at the bottom of the screen.

<u>**Slide 50 – Equivalent Steam Demand**</u>

When evaluating insulation projects in cogeneration systems significant care must be exercised because low-pressure steam will have a different worth than high-pressure steam. High-pressure steam is typically worth fuel cost divided by boiler efficiency. This is the method 3EPlus uses in the Cost of Energy calculation.

In cogeneration systems the impact cost of low-pressure steam can be less than one half the impact cost of high-pressure steam. We are referring to the true economic impact the site will experience by reducing the thermal loss at low-pressure.

In instances where the insulation project impacts steam that is not the same cost as high-pressure steam a slightly more complicated analysis is required. This analysis determines the impact the missing insulation has on the site steam demand. 3EPlus will be used in a similar manner to determine the energy savings from the insulation project. Then the energy impact will be converted into a steam system impact.

We will repeat our insulation example by considering that the steam header with the missing insulation is a medium-pressure steam header that is part of a plant that cogenerates. Because of the cogeneration aspects of the system reducing low-pressure or medium-pressure steam demand will not only impact fuel purchases but will also impact electrical purchases.

Consider that the steam supplied to this heat exchanger passes through the section of uninsulated pipe identified in the previous example. This uninsulated section of pipe becomes a part of the thermal load of the plant. In effect the thermal load of the heat exchanger has increased by the amount of heat transfer from the uninsulated pipe. This increase in thermal load has increased the amount of fuel required in the boiler. Additionally, this thermal load has impacted the amount of steam passing through the turbine supplying the medium-pressure system. As a result, the unit cost of medium-pressure steam should be used to determine the economic impact associated with insulating the header.

Therefore, we will use 3EPlus to determine the impact the uninsulated section of pipe has on thermal load. Then we will determine how much additional steam must be supplied to the heat exchanger because of the increased thermal load. The impact cost of steam will be used to identify the economic impact of installing the insulation.

[Slide Visual – Equivalent Steam Demand]

Heated material enters the left side of a heat exchange and exits the right side.

Steam supply enters the heat exchanger through a run of piping, mostly insulated, but there is a bare area approximately 20 feet long. An arrow indicates the bare pipe with the note 'Heat transfer loss from un-insulated pipe".

Condensate exits the heat exchanger at the bottom through a steam trap.

An insert photo of the bare piping is located in the upper right hand corner of the slide.
A photograph of an industrial pipe bridge is shown. The piping is somewhat congested but fairly typical of an industrial plant. One of the pipes, prominently displayed in the picture, is a steam header that has a section with no insulation. The un-insulated section has horizontal and

vertical runs. This run has four 90-degree elbows which allow the pipe to avoid an obstruction. The piping distribution runs from left to right, engages an elbow to allow the piping to be raised, then an elbow to allow the piping to run toward the viewer and over a structural member, engage another elbow to turn down to the original elevation, then another elbow to continue to advance to the right. The pipe at the left of the picture is observed to be insulated with a metal jacket covering the assembly. However, in a very short distance the insulation and covering are removed leaving the pipe un-insulated through the turns and straight sections. Insulation and jacketing are in-place on the pipe as it leaves the picture to the right.

Slide 51 – Insulation Savings

The previous 3EPlus evaluation identified the heat transfer from the uninsulated pipe and the heat transfer that will occur from the insulated pipe. The difference in these two values is the energy that will be saved if the pipe is insulated—this is the reduction in thermal load.

[Slide Visual – Equivalent Steam Demand – 3EPlus]

Cost of Energy –
Bare and Insulated Surfaces

Energy Tab
Item Description = Missing Insulation
System Units = ASTM C585
Geometry Description = Steel Pipe - Horizontal
Bare Surface Emittance = 0.8
Nominal Pipe Size = 10 in.
Process Temperature = 550 °F
Ave. Ambient Temperature = 70 °F
Ave. Wind Speed = 3 mph
Fuel Type: Natural Gas
Heat Content: 1000 BTU/cubic foot
Fuel Cost: 10.00 $/Mcf
Efficiency: 80 percent
Hours Per Year = 8760
Outer Jacket Material = Aluminum, oxidized, in service
Outer Surface Emittance = 0.1
Insulation Layer 1 = Calcium Silicate BLK+PIPE, Type I
Thickness: 3.08 in.

Append to Audit - Browse

Variable Insulation Thickness	Cost ($/ft/yr)	Heat Loss (Btu/ft/yr)	Savings ($/ft/yr)
Bare	636.90	50950000	
Layer 1	28.74	2300000	608.200

Slide 52 – Converted Steam Loss

A quick calculation indicates the uninsulated section of pipe increases the thermal demand by 111,000 BTU per hour.

[Slide Visual – Energy Loss Converted to Steam Loss Calculation 1]

$\text{Q-dot}_{total} = \text{q-dot}_{per\ length}\ L_{total}$

Heat Loss is the sum of the heat loss per length multiplied by the length of the item.

Q-dot_{total} = (50,950,000 Btu/yr-ft – 2,300,000 Btu/yr-ft) (20 feet) (1 year / 8,760 hrs)

Heat Loss equals 50,950,000 Btu/yr-ft minus 2,300,000 Btu/yr-ft; multiplied by 20 feet; multiplied by 1 year divided by 8,760 hrs.

Q-dot_{total} = 111,000 Btu/hr

Heat Loss equals 111,000 Btu per hour

Where:

Q-dot_{total} = Heat Loss
$q_{per\ length}$ = Heat Loss per unit length
L_{total} = Length

Slide 53 – Converted Steam Loss 2

The heat exchanger will require enough steam to satisfy this uninsulated section of pipe as well as the legitimate heat exchanger demand. This increase or impact in steam flow is determined through a first law of thermodynamics analysis of the un-insulated pipe and the heat exchanger. This is compared to the same heat exchanger load with the pipe insulated.

This additional steam demand will be eliminated when the pipe is insulated.

[Slide Visual – Energy Loss Converted to Steam Loss Calculation 2]

	Properties						
Location	Temp [°F]	P [psia]	Specific Volume [ft³/lbm]	Enthalpy [Btu/lbm]	Entropy [Btu/lbm°R]	Quality [%]	P [psig]
Medium Pressure	550	164.7	3.54075	1,298.86	1.67502	****	150
Saturated Vapor	366	164.7	2.75693	1,195.57	1.56726	100.0	150
Saturated Liquid	366	164.7	0.01818	338.36	0.52323	0.0	150

$$\text{m-dot}_{steam} = \frac{\text{Q-dot}_{total}}{(h_{steam} - h_{condensate})}$$

Mass flow rate of the steam is equal to the Total Heat Loss Converted to Steam divided by the difference in the enthalpy of the steam and the enthalpy of the condensate.

$$\text{m-dot}_{steam} = \frac{111{,}000 \text{ Btu/hr}}{(1{,}298.86 \text{ Btu/lbm} - 338.36 \text{ Btu/lbm})}$$

Mass flow rate of the steam is equal to 111,000 Btu/hr divided by the difference of 1,298.86 Btu/lbm minus 338.36 Btu/lbm.

m-dot_{steam} = 115 lbm/hr

Mass flow rate of the steam is equal to 115 pounds per hour.

Where:

m-dot_{steam} = Mass flow rate of steam generated in the boiler
h_{steam} = Enthalpy of the steam
$h_{condensate}$ = Enthalpy of the condensate
Q_{total} = Total Heat Loss

Slide 54 – Converted Steam Loss 3

The impact steam cost can be applied to this steam demand. Impact steam costs can be developed from steam system analyses like the ones completed with the SSAT software tool.

Again, this type of analysis is required for cogeneration systems—when the cost of steam is impacted by turbine operations. Often in cogeneration systems the impact cost of low-pressure steam is less than 50 percent of the cost of high-pressure steam.

[Slide Visual – Energy Loss Converted to Steam Loss Calculation]

K-dot$_{Steam}$ = m-dot$_{steam}$ k$_{steam}$

Impact Heat Loss is equal to the mass flow rate of the steam multiplied by the cost of the steam.

k$_{steam}$ is circled with a note "If the cost of steam is known."

K-dot$_{Steam}$ = (115 lbm/hr) (14.53 \$/10^3 lbm) = 1.68 \$/hr

Impact Heat Loss is equal to 115 pounds per hour multiplied by \$14.53 per 1,000 pounds of steam equal \$1.68 per hour.

K-dot$_{Steam}$ = 1.68 \$/hr (8760 hrs/1 yr) = 14,000 \$/yr

Impact Heat Loss is equal to \$1.68 per hour multiplied by 8,760 hours per year equals \$14,000 per year.

Where:
K-dot$_{Steam}$ = Impact Heat Loss Cost
m-dot$_{steam}$ = Mass flow rate of steam generated in the boiler
k$_{steam}$ = Cost per pound of steam (known)

Marginal Steam Costs	
(based on current operation)	
HP (\$/klb)	16.01
MP (\$/klb)	14.53
LP (\$/klb)	13.87

SSAT steam demand project can also be utilized

<u>Slide 55 - Condensate Loss</u>

Condensate recovery is a vital part of effective steam system management.

> ***[Slide Visual – Steam Distribution Losses –Condensate Loss]***
>
> **Banner:**
> **DOE's BestPractices**
> **Steam End User Training**
>
> **<u>Steam Distribution Losses</u>**
> **Steam Leaks – Pipe Failures and Trap Failures**
> **Heat Transfer Loss Through Insulation**
> **Condensate Loss**
> **Overall System**

<u>Slide 56 - Condensate Recovery</u>

Condensate is generally the cleanest water on the plant site—recovery of it can reduce boiler blowdown rates and reduce boiler chemical requirements. However, almost always the dominant worth of condensate is the thermal energy resident in it. Every pound of condensate that can be returned at 180 degrees Fahrenheit, for example, will eliminate the need to purchase a pound of makeup water at possibly 70 degrees Fahrenheit. The steam system would be required to heat the makeup water from 70 degrees Fahrenheit to 180 degrees Fahrenheit—the condensate would not require this energy expenditure.

> ***[Slide Visual – Condensate Recovery]***
>
> - **Condensate typically has an energy value**
> - **Make-up water typically has a value**
> - **Condensate recovery costs generally center on the recovery system piping**
> - **Increased condensate return reduces makeup water requirements, which generally improves feedwater quality**

<u>Slide 57 - Return Example 1</u>

We will explore a simple example that will identify the impacts associated with condensate recovery. In this example, a heat exchanger discharges 212 degrees Fahrenheit condensate straight to the sewer. We used a 5 gallon bucket and a stopwatch to measure the condensate flow to the drain. It took about 30 seconds for a 5 gallon bucket to fill up, which means the condensate flow is about 10 gallons per minute. This translates into about 5,000 pounds per hour of condensate that can be recovered. How beneficial is it to get this condensate back to the boiler and what would be required to recover the condensate?

[Slide Visual – Condensate Return Example]

The schematic depicts condensate return in a heat exchanger. Heated material and high pressure steam enter into the heat exchanger through several passes. Steam exits the heat exchanger through a steam trap and discharges to sewer.

- **Measured condensate temperature 212°F.**
- **Condensate flow measured by bucket and stopwatch (mass and energy balance is also a common method) to be 10 gallons/minute (5,000 lbm/hr)**

Slide 58 - Return Example 2

The classic condensate recovery method is to route the steam trap discharge to a vented condensate receiver. The receiver will be equipped with a pump and a level control device. The pump will transfer condensate from the receiver to the condensate return pipe and ultimately to the boiler. The condensate return piping and equipment should be insulated to ensure the thermal energy of the condensate is recovered.

[Slide Visual - Condensate Return Example 2]

The schematic depicts condensate return in a heat exchanger. Heated material and high pressure steam enter into the heat exchanger through several passes. Steam exits the heat exchanger through a steam trap and then routed to a vented condensate receiver. It is transferred to an insulated condensate return pipe and ultimately pumped to the boiler. A Level Controller senses the liquid level in the receiver.

- **The energy savings opportunity is based on the temperature of the condensate recovered into the boiler as compared to the temperature of makeup water**

Slide 59 - Return Example 3

It is assumed that the condensate will return to the boiler area with a temperature of 180 degrees Fahrenheit. We can use SSAT to quickly and accurately determine the system impact associated with returning this condensate; however, we will use the simple energy equations here as a first order estimate.

[Slide Visual - Condensate Return Example 3]

The schematic depicts condensate return in a heat exchanger. Heated material and high pressure steam enter into the heat exchanger through several passes. Steam exits the heat exchanger through a steam trap and then routed to a vented condensate receiver. The condensate temperature is 212 degrees Fahrenheit. It is transferred to an insulated condensate return pipe and ultimately pumped to the boiler. A Level Controller senses the liquid level in the receiver.

- **Condensate temperature entering boiler water system is 180°F**
- **Makeup water temperature is 70°F**

Slide 60 - Return Example 4

The calculation identifies the additional fuel the steam system will require to heat the makeup water from 70 degrees Fahrenheit to 180 degrees Fahrenheit—which is the temperature of the condensate as it returns to the boiler. The worth of the condensate from this one heat exchanger is 60,000 dollars per year of fuel purchases.

[Slide Visual - Condensate Cost Savings Equations]

$$o_{condensate} = \frac{\dot{m}_{condensate}\,(h_{condensate} - h_{makeup})\,T}{n_{boiler}}\,k_{fuel}$$

Condensate Cost Savings is equal to the mass flow rate of the condensate multiplied by the difference of the enthalpy of the condensate and the enthalpy of the makeup water; multiplied by the operating period; multiplied by the cost of fuel; all divided by the boiler efficiency.

$$o_{condensate} = 5{,}000\ \text{lbm/hr}(147.91\ \text{Btu/lbm} - 38.05\ \text{Btu/lbm})(8{,}760\ \text{hours/year})(10.0\ \$/10^6\text{Btu})(1/0.80)$$

Condensate Cost Savings is equal to 5,000 lbm/hr multiplied by 147.91 Btu/lbm minus 38.05 Btu/lbm; multiplied by 8,760 hours per year; multiplied by $10.00 per million Btu; all divided by 0.80.

$$o_{condensate} = 60{,}000\ \$/\text{year}$$

Condensate Value is equal t0 $60,000 per year.

Where:

$o_{condensate}$	= Condensate Cost Savings
m-dot$_{condensate}$	= Mass flow rate of condensate generated in the boiler
k_{fuel}	= Cost of the fuel
h_{makeup}	= Enthalpy is energy content of the makeup water
$h_{condensate}$	= Enthalpy is energy content of the condensate
n_{boiler}	= Boiler efficiency

Slide 61 - Condensate Recovery

Often condensate systems function poorly because they attempt to transport condensate and steam together. It must be understood that a significant amount of energy resides in the flash-steam collected in the condensate system. However, if there is no effective use of the flash-steam then it may be beneficial to simply vent the flash-steam through a local condensate receiver to allow effective recovery of the remaining condensate. This will allow us to pump water back into the boiler without the problems associated with transporting liquid and vapor together.

A common failure mode of condensate receivers is pump failure. Often the pump-receiver combination is improperly designed and the condensate actually boils as it enters the pump. This condition is identified as cavitation and is very detrimental to the life of the pump. Often condensate receiver-

pump arrangements are designed for less than 180 degrees Fahrenheit condensate. The cavitation problems develop from the fact that many steam traps discharge saturated liquid condensate, which will be 212 degrees Fahrenheit as it enters the receiver (assuming standard atmospheric pressure).

Most condensate recovery systems must be designed with an elevated receiver and the pumps well below the receiver to ensure sufficient static pressure to eliminate the possibility of boiling in the pump.

Slide 62 - Cascade Condensate Systems

If we have an opportunity to utilize the flash steam collected in the condensate system then this can greatly improve the energy efficiency of the steam system. Cascade condensate collection systems can make excellent use of the thermal energy resident in the flash steam. Additionally, cascade condensate collection systems minimize the impact of failed steam traps because live steam is directed to the lower pressure steam systems.

[Slide Visual – Cascade Condensate Systems]

The schematic depicts condensate return in a heat exchanger. Heated material and high pressure steam enter into the heat exchanger through several passes. Steam exits the heat exchanger through a steam trap. Condensate and steam from the steam trap, along with steam from additional steam traps, are collected in a condensate receiver tank with a level controller. Steam is then sent to the Low Pressure Steam System. Condensate is sent to the condensate system and may or may not be pumped.

Slide 63 - Overall System

At this point we want to draw our attention to an energy efficiency improvement strategy that is often recommended for steam system management.

[Slide Visual – Steam Distribution Losses –Overall System]

Banner:
DOE's BestPractices
Steam End User Training

Steam Distribution Losses
Steam Leaks – Pipe Failures and Trap Failures
Heat Transfer Loss Through Insulation
Condensate Loss
Overall System

Slide 64 - Pressure Reduction 1

It is commonly recommended to reduce the steam system operating pressure to reduce operating costs. This is only attractive in systems that do not cogenerate—reducing the steam generation pressure of cogenerating systems is almost always counter-productive. However, when considering steam systems that do not have cogeneration components, reducing the operating pressure can reduce energy requirements.

[Slide Visual – Steam Pressure Reduction]

- **When steam is produced for heating purposes only, what benefit would be gained if boiler pressure were reduced?**

Slide 65 - Pressure Reduction 2

Some of the primary energy reductions result in the distribution system and arise from reduced leaks and reduced heat transfer losses. For example, if steam is distributed throughout the system at 150 PSIG rather than 200 PSIG then any leak will pass 30 percent less steam. Similarly, a failed steam trap will discharge less steam.

As the steam pressure is reduced, the saturation temperature of the steam is reduced. Steam systems that distribute saturated steam throughout the system will experience less heat transfer loss because of this reduced distribution temperature. Even systems that distribute superheated steam can possibly experience reduced heat transfer loss. Distributing 150 psig saturated steam will result in 7percent less heat transfer losses than distributing 200 psig saturated steam.

Additionally, as condensate is formed and collected it is typically passed through a steam trap to a condensate collection system. As the condensate enters the low-pressure condensate collection system some flash steam forms. Often this flash steam is exhausted from the system. When steam pressure is reduced the amount of flash steam generated in the condensate system is reduced.

Most often the largest potential impact associated with reducing steam pressure is an improvement in boiler efficiency. Boiler efficiency improves because the boiling temperature of the water reduces as steam pressure is reduced. In other words, there is a larger temperature difference between the boiling water and the flue gases, which allows more heat transfer. This will result in a reduced flue gas exit temperature and improved boiler efficiency.

It is not known exactly how an individual boiler will respond to reducing steam generation pressure but an estimate of the maximum expected decrease in flue gas temperature is the decrease in boiling temperature of the water in the boiler. As an example, consider a steam generation pressure that is originally 200 PSIG. The boiling temperature of the boiler water is nominally 388 degrees Fahrenheit for this condition. The boiling temperature of the water operating at 150 PSIG is 366 degrees Fahrenheit. As a result, the maximum flue gas temperature reduction is estimated to be 22 degrees Fahrenheit. The maximum impact on boiler efficiency is 0.6 percent. Generally, the actual impact will be less than this value. Therefore, care must be exercised in using this estimate. The presence of flue gas energy recovery components will decrease the impact on boiler efficiency.

It should be noted that the steam end-use components will continue to require the same thermal energy when supplied high-pressure steam or low-pressure steam. As a result, the mass flow rate of steam supplied to the end-use equipment may change.

[Slide Visual – Steam Pressure Reduction]

- **When steam is produced for heating purposes only, what benefit would be gained if boiler pressure were reduced?**
  - **Boiler efficiency improvement**
  - **Heat transfer losses are reduced**
  - **Leak losses are reduced**
  - **Condensate system flash steam losses are reduced**
    - **If the steam loads receive reduced pressure steam**

Slide 66 - Pressure Reduction Study 1

Let's examine the impacts experienced on a real steam system. The steam system in question is already operating at relatively low-pressure but it is the design condition of the system. Measurements indicated the system pressure averaged 54 PSIG initially. The pressure was reduced to 30 PSIG. The saturation temperature of the steam decreased from 301 degrees Fahrenheit to 274 degrees Fahrenheit—a 27 degrees Fahrenheit reduction in steam temperature. The flue gas temperature decreased 25 degrees Fahrenheit. The boiler was burning number 2 fuel oil and the efficiency improved 1 percentage point.

Slide 67 - Pressure Reduction Study 2

The heat transfer loss from the piping system decreased 10 percent. All steam leaks decreased 30 percent.

Even though the boiler efficiency impact is only one percent in this example it is very significant. This is because all of the fuel energy is exposed to this one percent change; as a result, the total fuel cost will be impacted by this change. Typically the boiler efficiency impact is the most significant from an economic standpoint.

The savings potentials from leaks, insulation losses, and condensate flash steam loss sound significant—and they can be significant; however, several factors should be considered. First, leaks should be managed to a small fraction of the total steam supply. Leaks that do exist will decrease but leaks are typically a small portion of the system demands.

Second, heat transfer losses from the distribution system will decrease as the steam temperature decreases. However, the distribution system should be insulated resulting in minimal system heat transfer loss even in systems with miles of steam piping.

Third, the condensate flash steam loss reduction only occurs on unregulated steam loads. In other words, if a steam trap is serving a heat exchanger that is controlled with a steam control valve then the pressure of the condensate as it passes through the trap will not be influenced by the steam distribution pressure. Often it is only the traps serving the main distribution piping that reduce their flash-steam loading when steam pressure is decreased.

Slide 68 - Pressure Reduction 1

There are several points of concern when considering reducing steam pressure.

[Slide Visual – Steam Pressure Reduction]

- **What are the major problems associated with reducing system pressure?**

Slide 69 - Pressure Reduction 2

The savings potential can be significantly diminished if the lower boiler pressure results in liquid carryover from the boiler. As the boiler pressure is reduced the relative steam velocity in the boiler increases for a given boiler load. This increases the potential for liquid carryover, which can result in loss of boiler chemicals and can present a mass loss from the system as the liquid flashes through the condensate collection system. Carryover can also harm downstream components by causing water-hammer and component erosion.

[Slide Visual – Steam Pressure Reduction]

- **What are the major problems associated with reducing system pressure?**
  - **Boiler carryover potential increases**
    - **Water-hammer**
    - **Increased water treatment costs**
    - **Poor boiler water chemistry control**
    - **Equipment fouling**
      - **Equipment corrosion**
    - **Equipment erosion**
    - **Energy loss**

Slide 70 - Pressure Reduction 3

The reduced density of the lower pressure steam will result in increased velocities in the distribution system. This can decrease steam pressures throughout the system and limit steam supply to critical components.

Many steam trap and condensate collection systems rely on steam pressure to move the condensate through the collection components. The capacity of all steam traps is directly related to steam pressure. Reducing the steam supply pressure can result in a mal-functioning condensate collection system.

Additionally, most steam heat exchangers and many other components control steam flow by throttling the steam based on demand requirements. If these components operate with a reduced pressure then the flash steam savings noted will not occur.

Also, consideration should be given to the fact that heat transfer losses should not be a major load; in other words, the steam system should be well insulated. Steam leaks should be minimized as well.

These factors reduce the potential impact of reducing steam pressure.

[Slide Visual – Steam Pressure Reduction]

- **What are the major problems associated with reducing system pressure?**
- **Steam supply problems resulting from increased frictional loss**
  - **Pipe diameter may not be sufficient to supply the steam demand**
  - **Valve size**
- **Condensate recovery and return issues resulting from reduced driving pressure**
- **Heat exchanger temperature difference reduces limiting heat transfer**

Slide 71 - Pressure Reduction 4

There are many issues to consider when examining steam pressure reduction. There are many potential benefits and just as many potential pitfalls.

[Slide Visual – Steam Pressure Reduction]

- **Boiler carryover can become a very serious problem resulting from reducing system pressure**
  - **Equipment fouling**
  - **Equipment erosion**
  - **Energy loss**
  - **Water hammer**
  - **Water treatment costs**
- **Pressure reduction can be accomplished after the boiler**
  - **Boiler efficiency improvement will not be attained**
    - **Boiler efficiency improvement is typically the largest impact**

Slide 72 - Pressure Reduction Caution

As a result, the decision to reduce steam system operating pressure should be thoroughly investigated.

[Slide Visual – Steam Pressure Reduction]

- **Exercise caution when implementing this activity**
  - **There are many potential problems**
  - **System pressure reduction is a common recommendation**

This recommendation may not receive as much evaluation as necessary

Slide 73 – Steam Distribution Losses - Summary

In summary, there are several factors that can contribute to significant losses in the steam distribution system. Periodic evaluation and investigations can help identify areas of opportunities to help achieve an efficient steam generation and distribution system.

[Slide Visual – Steam Distribution Losses - Summary]

- **Repair/Replacement**
  - **Steam Leaks**
  - **Pipe Failures**
  - **Damaged/Missing Insulation**
- **Steam Trap Management Program**
- **Condensate Recovery**
- **Steam Pressure Reduction**